Chapter 1: The World of Energy, Introduction to Physics 1104

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1.1 Introduction to the World of Energy

The World of Energy courses explore the basic principles of physics in the context of energy use. The courses include practical examples from everyday life to help you use energy safely and wisely. They help prepare you to make rational, informed decisions regarding energy policy, the environment, and your own place in the changing World of Energy. The World of Energy courses, Physics 1103 and 1104, are each a three-semester credit hour course that fulfills the GEC physical science requirement for the Bachelor of Arts degree at The Ohio State University. Physics 1103 and 1104 are non-sequential: students may take Physics 1104 without having taken Physics 1103.

The World of Energy uses a hands-on approach to investigate physics concepts, energy use, and the effects of its use on our environment. Through class activities and demonstrations, the World of Energy gives students an opportunity to experience first hand the laws of physics. Physics concepts are conveyed by your instructor, this textbook, and activity sheets completed during class.

Class Activities/Activity Sheets

During two 80-minute classes per week, your instructor will explain physics concepts, present demonstrations, and introduce hands-on activities to illustrate these concepts. To help organize, understand, and remember the information from the demonstrations and class activities, students complete and turn in activity sheets during each class. Students must be present for the full class period to receive credit for an activity sheet unless excused by the instructor. Activity sheets are found on the Physics 1104 web site: www.physics.ohio-state.edu/phys1104/

Exercises

Following each activity sheet is a page of exercises to be completed and handed in. At the beginning of each class period, students turn in a completed Exercise sheet for the previous period. For example, at the beginning of the class when Period 2 will be taught, students turn in a completed Period 1 Exercise sheet.

Several multiple choice questions for each chapter and their solutions will be posted on the course web site. Students do not turn in answers to the multiple choice questions. However, these questions may illustrate concepts or provide hints for the homework exercises described in the previous paragraph.
Videos
Outside of class time, students will view six 50-minute videos related to the course material. These videos explain physics principles and help relate these principles to the role of energy in everyday life. A list of questions for each video will be posted on the course web site. Students do not turn in answers to these questions. These questions are provided to help students identify important concepts in the videos. DVDs of the videos are available on closed reserve at the OSU Science and Engineering Library. Midterm and final exams will include one question based on the material in each of the six videos.

Examinations
The course examinations consist of two midterms of 33 questions each and a comprehensive final examination of 50 questions. All exam questions are multiple choice. The dates of the examinations are given in the course syllabus. No make-up examinations will be given. Students who have a time conflict with any of the exam times should notify the instructor immediately.

Students may use calculators during exams, but may not program them or use their graphing capabilities. Exams include a sheet with useful equations and constants. Equation sheets are provided because the World of Energy emphasizes understanding concepts, rather than memorizing equations and constants. However, it is essential that students understand the meaning of the equations, their symbols, and their units. Part Practice exams with equation sheets will be posted on the course web site. The textbook provides help in understanding equations and solving problems in the Skills and Strategies and Concept Check sections.

Textbook
Each chapter of this textbook corresponds to one class period. These chapters will be posted on the course web site. To get the most benefit from class, students should read the text prior to each class. The text contains Concept Check questions to check your understanding of the material. If you cannot answer a Concept Check question, reread the text, review the examples, and study the Skills and Strategies help boxes. Answers to the Concept Check questions are given at the end of each chapter.

How to Succeed in The World of Energy
In the World of Energy, students learn physics concepts primarily by doing activities in class, observing instructor demonstrations, and participating in class discussions. While your textbook contains important information and should be read before each class, it does not provide all the information you will need – some physics concepts have been left for you to discover in your classroom activities. Therefore, class attendance and active participation is very important.

In the World of Energy we will explore different forms of energy and the many ways in which energy is used to do work. We begin by discussing some of the mathematical tools used in the course.
1.2 Ratios

To simplify comparisons among quantities, information is often presented as a ratio. A ratio is a fraction – one quantity divided by another quantity. The word *per* means *for each* and designates a ratio.

**Ratios and Unit Conversions**

An important use of ratios is the conversion of a quantity from one unit into another. Ratios formed from any two equivalent quantities, such as 60 min = 1 hour or 365 days = 1 year are just another way of writing unity, or one, and can be used to convert units. Multiplying a quantity by such a ratio does not change the value of the quantity, but merely changes the units in which that value is expressed. For example, to convert from hours to minutes, use a ratio to cancel the unit you wish to eliminate.

\[
3 \text{ hours} \times \frac{60 \text{ min}}{1 \text{ hour}} = 180 \text{ min}
\]

(Example 1.1)

There are 1,609 meters per 1 mile. Use ratios to convert 60 miles per hour into meters per second.

\[
\frac{60 \text{ miles}}{1 \text{ hour}} \times \frac{1,609 \text{ meters}}{1 \text{ mile}} \times \frac{1 \text{ hour}}{60 \text{ min}} \times \frac{1 \text{ min}}{60 \text{ sec}} = 27 \text{ meters/ sec}
\]

**Ratios and Efficiency**

Another common use of ratios is to represent the efficiency of an energy conversion process. The efficiency of an energy conversion process is the ratio of the amount of energy of the desired type produced divided by the total amount of energy put into the conversion process. This ratio may be expressed as a fraction, as a decimal, or as a percent. Equation 1.1 below and Figure 1.1 describe this relationship.

\[
\text{Efficiency} = \frac{\text{Useful Energy (or Power) Out}}{\text{Total Energy (or Power) In}}
\]  

(Equation 1.1)

**Fig. 1.1 Efficiency of an Energy Conversion**
In any energy conversion process,

**Total Energy In = Useful Energy Out + Wasted Energy Out**

When a series of energy conversions is required to produce the desired form of energy, energy is wasted in each step of the process. The overall efficiency of a series of energy conversion processes can be quite low. The overall efficiency is the product of the efficiencies of each step in the process.

\[
\text{Overall Efficiency} = (\text{Efficiency of step 1}) \times (\text{Efficiency of step 2}) \times (\text{Efficiency of step 3}) \times \ldots
\]

or

\[
\text{Overall Efficiency} = \text{Eff}_1 \times \text{Eff}_2 \times \text{Eff}_3 \times \ldots \quad \text{(Equation 1.2)}
\]

Efficiencies given as a percent must be converted to a decimal before performing the multiplication indicated above.

### 1.3 Scientific Notation (Powers of Ten)

A number in *scientific notation* is written as a number with one digit to the left of the decimal point times 10 raised to an exponential power. When any number is raised to an exponential power, that number is called the base. Scientific notation uses the base 10 and is sometimes called *powers of 10* notation. Scientific notation is useful when considering very large or very small numbers.

- Mass of the Earth = \(5.98 \times 10^{24}\) kg
- Universal gravitational constant, \(G = 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2\)
- Radius of a proton = \(1 \times 10^{-15}\) m

When converting any number to scientific notation, the exponent of base 10 is found by counting the number of places the decimal point is shifted to the left for positive exponents or shifted to the right for negative exponents. A positive exponent of 10 indicates how many times the base 10 is multiplied by itself. A negative exponent indicates how many times 1 is divided by 10. Any number to the power zero equals one.

\[
\begin{align*}
10^2 &= 10 \times 10 &= 100 \\
10^1 &= 10 \\
10^0 &= 1 \\
10^{-1} &= 1/10 &= 0.1 \\
10^{-2} &= 1/(10 \times 10) &= 0.01
\end{align*}
\]
Table 1.1: Rules for Using Scientific Notation

1. When multiplying powers of 10, add their exponents.
\[ 10^A \times 10^B = 10^{(A + B)} \]

2. When dividing powers of 10, subtract their exponents.
\[ 10^A / 10^B = 10^{(A - B)} \]

3. When raising a power of 10 to a power, multiply the exponents.
\[ (10^A)^B = 10^{(A \times B)} \]

4. Any number raised to the power zero equals 1.
\[ A^0 = 1 \quad 10^0 = 1; \quad 27^0 = 1 \]

1.4 Linear and Exponential Growth
A growth rate is the ratio of the amount of increase to the time elapsed. Figure 1.2 on the next page illustrates two common models for growth rates – linear growth and exponential growth. It also illustrates what happens when a quantity decreases exponentially with time – exponential decay.

In Figure 1.2, the graph of population is a straight line, which has a constant slope. Graphs with a constant positive slope represent linear growth. Linear growth is characterized by the addition of a constant amount during a fixed time period. The equation describing linear growth is

\[ N = A \times t + B \]

where
\[ N = \text{the amount of the quantity at a given time} \]
\[ A = \text{the amount of increase per time period} \]
\[ t = \text{the number of time periods elapsed} \]
\[ B = \text{the initial amount of the quantity} \]

Concept Check 1.1
A population of 12,500 people increases by 25 people per year. What will the population be 12 years from now?

________________
Fig. 1.2 Sample Data on Population and Energy Use

The graph of energy use in Figure 1.2 illustrates exponential growth. An exponential growth graph is not a straight line because the amount of the increase per time period is not constant. Exponential growth is characterized by a doubling of the amount of the quantity during a fixed time period. The time between doublings is called the doubling time. Since the amount increases by a factor of two, exponential growth is described by base 2 raised to an exponential power equal to the number $a$ of time periods elapsed. The equation describing exponential growth is

$$N = B \times 2^t$$

(Equation 1.4)

where

- $N$ = the amount of the quantity at a given time
- $t$ = the number of time periods elapsed
- $B$ = the initial amount of the quantity
Concept Check 1.2

a) A town uses 7,500 MJ of energy per year. If the energy use doubles every 5 years, how much energy would the town require 20 years from now?

_________________

b) Another town used 40,000 MJ of energy from wood in 1950. If the amount of wood used decreases by a factor of two every 10 years, how much energy from wood did this town use in 2000?

_________________

When carrying out the calculation in part b of Concept Check 1.2, it is necessary to count backwards in time from 1990 to 1950. When a quantity decreases exponentially with time, the variable $t$ is the number of halving times instead of the number of doubling times. When a quantity decreases exponentially, Equation 1.4 is written with a negative exponent of $t$, as shown in Equation 1.5.

\[ N = B \times 2^{-t} \]  

(Equation 1.5)

Dependence on particular energy sources in the U.S. has changed over the past century. Figure 1.3 on the next page illustrates the growth of electrical energy production in the U.S. from 1950 to 2000 and the energy sources for this electricity.
Figure 1.3  Annual Electricity Production in the U.S. by Type of Fuel

Concept Check 1.3

a) Between 1950 and 1970, what type of growth best represents the graph of electricity production from all fuels in Figure 1.3? ______________________

b) If this growth rate had continued, what would the energy production have been in 1980? _______________ in 1990? _______________

c) Between 1975 and 1995, what type of growth best represents the graph of electricity production from all fuels? ______________________

d) If this growth rate continues, what would the electricity production from all fuels be in 2005? _______________ in 2015? _______________
Exponential growth and decay rates have many applications in business and finance and in physical and biological systems. The length of time for a quantity to double, the doubling time, is particularly important. Table 1.2 gives the doubling time in years for various growth rates when compounded annually.

Table 1.2: Growth Rates and Doubling Times

<table>
<thead>
<tr>
<th>Annual Growth Rate (in percent)</th>
<th>Doubling Time (in years)</th>
<th>Annual Growth Rate (in percent)</th>
<th>Doubling Time (in years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Infinite</td>
<td>20</td>
<td>3.8</td>
</tr>
<tr>
<td>1</td>
<td>69.7</td>
<td>30</td>
<td>2.6</td>
</tr>
<tr>
<td>2</td>
<td>35.0</td>
<td>40</td>
<td>2.1</td>
</tr>
<tr>
<td>3</td>
<td>23.4</td>
<td>50</td>
<td>1.7</td>
</tr>
<tr>
<td>4</td>
<td>17.7</td>
<td>60</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>14.2</td>
<td>70</td>
<td>1.3</td>
</tr>
<tr>
<td>6</td>
<td>11.9</td>
<td>80</td>
<td>1.2</td>
</tr>
<tr>
<td>7</td>
<td>10.2</td>
<td>90</td>
<td>1.1</td>
</tr>
<tr>
<td>8</td>
<td>9.0</td>
<td>100</td>
<td>1.0</td>
</tr>
<tr>
<td>9</td>
<td>8.0</td>
<td>200</td>
<td>0.6</td>
</tr>
<tr>
<td>10</td>
<td>7.3</td>
<td>300</td>
<td>0.5</td>
</tr>
<tr>
<td>12</td>
<td>6.1</td>
<td>400</td>
<td>0.4</td>
</tr>
<tr>
<td>14</td>
<td>5.3</td>
<td>900</td>
<td>0.3</td>
</tr>
<tr>
<td>16</td>
<td>4.7</td>
<td>9900</td>
<td>0.15</td>
</tr>
<tr>
<td>18</td>
<td>4.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Concept Check 1.4

a) If you invest $5,000 at 8% interest compounded annually, how long will it take for your money to double to $10,000? ________

b) If a stock doubles in value every 4.2 years, what is its rate of growth? ________
Period 1 Summary

1.1: The World of Energy presents physics concepts in the context of energy use. The hands-on format of the course makes student class participation especially important.

1.2: The concept of *per* is represented by a ratio – one quantity divided by another quantity. When converting units, use ratios that allow cancellation of the unwanted units.

The efficiency of an energy conversion process equals the amount of energy of the desired type produced per total amount of energy put into the process.

\[ \text{Efficiency} = \frac{\text{Useful Energy Out}}{\text{Total Energy In}} \]

Ratio reasoning is a mathematical tool that allows you to solve practical problems using ratios.

1.3: Powers of 10 simplify calculations with very large or small numbers.

When multiplying powers of 10, add exponents.
When dividing powers of 10, subtract exponents.

1.4: Linear growth adds a constant amount of a quantity during each time period

Linear growth is expressed by \[ N = A \times t + B \]

Exponential growth doubles the amount of the quantity during each time period.

Exponential growth is expressed by \[ N = B \times 2^t \]

Exponential decay is expressed by \[ N = B \times 2^{-t} \]

where \( N \) = the amount of the quantity
\( A \) = the amount of increase per time period
\( B \) = the initial amount
\( t \) = the number of time periods elapsed

The doubling time for exponential growth is the length of time required for the amount of a quantity to double. Growth rate tables (Table 1.2) provide an easy way to determine growth rates and doubling times.
Solutions to Chapter 1 Concept Checks

1.1
The constant rate of increase (25 people per year) indicates linear growth. Use Equation 1.3 to find the population after 12 years.

\[ N = A \times t + B = (25 \text{ people/year} \times 12 \text{ years}) + 12,500 = 12,800 \text{ people} \]

1.2
a) The doubling time is 5 years, so the amount will double four times within 20 years as shown in the table below.

<table>
<thead>
<tr>
<th>Time</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>now</td>
<td>7,500 MJ/year</td>
</tr>
<tr>
<td>5 years from now</td>
<td>15,000 MJ/year</td>
</tr>
<tr>
<td>10 years from now</td>
<td>30,000 MJ/year</td>
</tr>
<tr>
<td>15 years from now</td>
<td>60,000 MJ/year</td>
</tr>
<tr>
<td>20 years from now</td>
<td>120,000 MJ/year</td>
</tr>
</tbody>
</table>

Or, using Equation 1.4, we find

\[ N = B \times 2^t = 7,500 \text{ MJ/yr} \times 2^4 = 7,500 \text{ MJ/yr} \times 16 = 120,000 \text{ MJ/yr} \]

b) The question has a halving time of 10 years, so the amount decreased by a factor of \( \frac{1}{2} \) every 10 years.

<table>
<thead>
<tr>
<th>Time</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>40,000 MJ/year</td>
</tr>
<tr>
<td>1960</td>
<td>20,000 MJ/year</td>
</tr>
<tr>
<td>1970</td>
<td>10,000 MJ/year</td>
</tr>
<tr>
<td>1980</td>
<td>5,000 MJ/year</td>
</tr>
<tr>
<td>1990</td>
<td>2,500 MJ/year</td>
</tr>
<tr>
<td>2000</td>
<td>1,250 MJ/year</td>
</tr>
</tbody>
</table>

Or, using Equation 1.5, we find

\[ N = B \times 2^{-t} = 40,000 \text{ MJ/yr} \times 2^{-5} = 40,000 \text{ MJ/yr} \times \frac{1}{2^5} = 40,000 \text{ MJ/yr} \times \frac{1}{32} = 1,250 \text{ MJ/yr} \]

(Note that \( 2^{-5} = \frac{1}{2^5} \))
1.3

a) Between 1950 and 1970, electricity production from all fuels approximately doubled each 10 years. Therefore, the graph represents exponential growth with a doubling time of 10 years.

b) Production would have doubled from 1,500 billion kWh in 1970 to 3,000 billion kWh in 1980 and would have doubled again to 6,000 billion kWh in 1990.

c) Between 1975 and 1985, electricity production from all fuels increased by approximately 500 billion kWh. Between 1985 and 1995, production again increased by approximately 500 billion kWh. Therefore, the graph represents linear growth, with 500 billion kWh added every 10 years.

d) By 2005, production would increase by 500 billion kWh to 3,500 billion kWh. By 2015, production would increase by another 500 billion kWh to 4,000 billion kWh.

1.4

a) From Table 1.2, the doubling time for a 8% growth rate is 9.0 years.

b) A doubling time of 4.2 years occurs with an 18% growth rate.